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FIXATION OPTOKINETIC NYSTAGMUS (FOKN) AND ITS MECHANISMS

Yu. B. Gippenreyter and V. Ya. Romanov

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16. Abstract

Experiments are described and evaluated in which a subject's eye movements were recorded as he fixed on a stationary point against a moving background. These involuntary eye movements constitute fixation optokinetic nystagmus (FOKN). The characteristics of FOKN depend on the relation between the direction of the asymmetry of physiological nystagmus and the direction of the moving background. When these directions are the same, FOKN has the form of stimulated physiological nystagmus; when the directions are opposite, it has the form of suppressed physiological nystagmus. Results reveal the subcortical nature of FOKN.

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FIXATION OPTOKINETIC NYSTAGMUS (FOKN) AND ITS MECHANISMS

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This article is a summary of partly published [4] and also new /26*
data, concerning the properties and mechanisms of fixation optokinetic nystagmus (FOKN). FOKN is involuntary movement of the eyes, arising upon fixing on a stationary object, against a background of moving contrasts.

The existence of FOKN was first reported in the work of M. Fisher and A. Kornmiller [13]. These authors, studying the mechanism of perception of movement, under conditions of optokinetic stimulation, placed the subject inside a rotating drum with black-white stripes. The subject was asked to fix on a stationary spoke, located in front of the moving stripes. Visually observing the eyes of the subject, they detected nystagmoid movements and gave a description of them. We present a brief excerpt from it.

"...If these unique eye movements are now compared with optokinetic nystagmus (OKN), it must be recognized that, abstracting from the quantitative differences, there are no outward differences. There also is an exchange of rapid phases and slow, smooth tracking movements here... Therefore, phenomenologically, we, if you please, could consider these movements to be a partial case of OKN. Beyond any doubt, they also are caused optokinetically. In order to distinguish their singularities, it is advisable to call them "fixation optokinetic nystagmus...".[1]

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*Numbers in the margin indicate pagination in the foreign text.

[1] M. Fisher and A. Kornmiller, "Involuntary optokinetic movement perception and optokinetic nystagmus," Journ. für Psych. und Neurol. 41/5, 273-308 (1930-31).

However, neither these nor other authors made objective recordings of FOKN. Therefore, its characteristics and mechanisms have remained unstudied up to the present time. Moreover, with the exception of Ter-Braak [20], who, referring to the report of Fisher and Kornmiller, expressed the hypothesis of a low-level, subcortical nature of FOKN, nearly all authors generally deny this type of eye movement. In the most well-known modern handbooks on neuroophthalmology, we encounter, for example, the following expressions: "...OKN can be abolished, if the subject fixes some stationary object during optokinetic stimulation or will simply imagine it" [21]; or "If the subject will fix his attention on some stationary object and not on the moving drum, OKN disappears" [17]. The reason for such a negative conclusion was insufficient resolving power of the methods of recording eye movements. In the majority of cases, this was such a quite low-sensitivity method as electrooculography. /27

We used a more sensitive technique of recording eye movements, which permitted FOKN recordings to be obtained for the first time and its properties to be studied.

METHOD

The subject was placed in front of a screen, on which an image was projected from one projector, of horizontally moving vertical black-white stripes and, through another, a stationary light point. The widths of the black and white stripes were identical at 4°. The subject received instructions to fix the stationary point.

The test was accompanied by recording of the horizontal components of eye movements, by use of a photooptic technique [8]. The resolution of the recording technique was 1 angular minute per mm of recording. The rate of movement of the photographic paper was 4 cm/sec.

Several series of experiments were conducted, in which the following conditions were variable: 1) direction of movement of the stripes, left to right and right to left; 2) rate of movement of the stripes; eight rates, between 14 and 240 deg/sec were selected in all:

V_1 = 14 deg/sec	V_5 = 82 deg/sec
V_2 = 26 deg/sec	V_6 = 140 deg/sec
V_3 = 36 deg/sec	V_7 = 178 deg/sec
V_4 = 47 deg/sec	V_8 = 240 deg/sec;

3) stripe frequency (number of stripes passing through the fixation /28 point in one minute); it changed simultaneously with the rate, from 40 to 690 stripe/min; 4) the physical characteristics of the fixation point: its size and brightness simultaneously. The brightness was changed on a subjective scale: "bright," "medium," "faint"; the dimensions were 16, 7-8 and 2-3 angular minutes, respectively. Recordings also were made with an invisible point; 5) in supplementary tests (with two subjects), the condition of the subjects was changed: the normal and alcoholic intoxication states were compared.

In each test, before turning on the moving stripes, the eye movement was recorded, while fixing the stationary point on a stationary background. These recordings were necessary, for comparison of the fixation eye movements with the moving and stationary backgrounds. The eye movements also were recorded with moving stripes and the task of tracking them (i.e., OKN recording).

All these were conducted with binocular vision. Nine subjects participated in the tests, with each of them having at least 3 tests in each condition. As a result, 700-900 FOKN cycles were obtained and processed for each subject under each condition.

RESULTS AND DISCUSSION

DEPENDENCE OF FOKN ON ASYMMETRY OF PHYSIOLOGICAL NYSTAGMUS (PN)

As is well-known, involuntary eye movements while fixing a stationary point includes slow drifts, at a rate on the order of 5-6 angular min/sec, interrupted by jumps in the opposite direction, with amplitudes up to 20' [19, 12, 8]. This was the basis for frequently calling them "physiological nystagmus" (PN). Although the drift is considered to be a random movement, accomplished in any direction [19, 8, 3], an asymmetry of these movements was found in the majority of our subjects, upon analysis of the PN. It consisted of the predominance of one of the two drift directions (and, correspondingly, the return jumps): right or left.[1] True, this asymmetry was not observed in some of the subjects. On this basis, we divided all the subjects into three groups: "right side" (drifts predominantly to the right, jumps to the left), "left side" (drifts to the left, /29 jumps to the right) and "centrists" (absence of predominance of any direction of drift and jump). PN recordings of representatives of each of the groups described are presented in Fig. 1. The variation curves of the PN drift amplitude distribution of these same subjects are given in Fig. 2 (solid line). Shifts of the curves, with respect to the zero point are seen, corresponding to the absence of lateral displacement: a--to the right (right side subject), b--to the left (left side subject) and c, curve is symmetric (centrist). Upon turning on the moving contrasts and retaining the instructions to fix the stationary point, changes of the fixation eye movements were observed in all submects, without exception. The nature of these changes was determined by coincidence or non-coincidence of the direction of the initial PN asymmetry with the direction of movement of the contrasts. If these directions coincided, an unusual "swing" of the PN was observed: the drift rate and amplitude increased (correspondingly, the return jump amplitude) and their

[1] We recall that the horizontal components of the eye movements were recorded in the tests described.

length decreased. This effect coincided with the results of the observations of M. Fisher and A. Kornmiller. Therefore, we designated the type of movement described as "typical FOKN." If the direction of movement of the background and the PN drifts did not coincide, in contrast, PN "suppression" was observed: a decrease in drift rate and amplitude (correspondingly, jump amplitude) and a strong increase in their lengths (Fig. 3,A, a, b). Movement of the stripes in each of the horizontal directions caused a swing of the PN of the centrists in the same direction (Fig. 3, A, c). Statistical processing of this result is presented in the FOKN drift amplitude distribution curves (the dot-dash and dashed lines in Fig. 2).

A more attentive study of the results obtained for the centrists showed, however, that these subjects are latent asymmetrics. The latter was disclosed by the tendency of the FOKN drifts to be more subject to one of the directions of the moving contrasts. This fact is represented in the "average cycles"[1] in Fig. 3B (subject IM). It is evident from the figure that the left FOKN cycle of this subject is characterized by a higher rate and amplitude than the right. Similar average cycles of the rightward and leftward stripe movement /32 of the asymmetric subjects (subject RM, subject ML) are presented in the same Fig. 3B. It is evident from the figure that the differences between the right and left FOKN are expressed more strongly here than by the centrists.

All subsequent work was based primarily on recordings of the typical FOKN. For this, the side of each subject was found before-

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[1]Each average cycle is constituted, on the basis of the average values of the amplitudes (l), duration (t) and rates $\left(v_{av} = \frac{e_{av}}{t_{av}}\right)$ of the FOKN drifts for a given subject, under given conditions. These values are presented above the triangles, which are the graphic images of the average cycles. The vertical legs of the triangles depict the average length, the horizontal ones, the average amplitude and the angle between the vertical leg and the hypotenuse, the average angular drift rate.

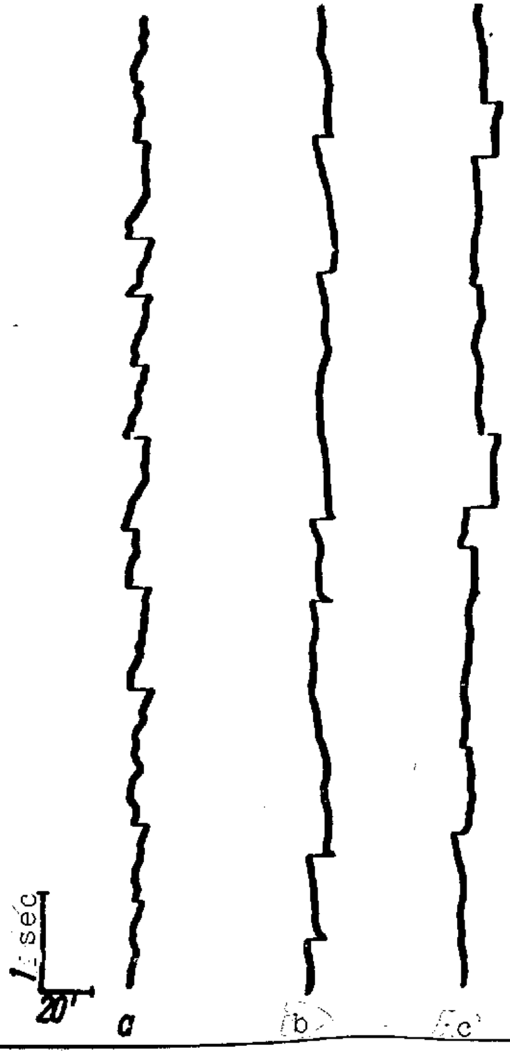

Fig. 1. PN recordings: a--right side subject (subject RM); b--left side subject (subject ML); c--centrist (subject IM). The time course in all recordings in this article is from bottom to top.

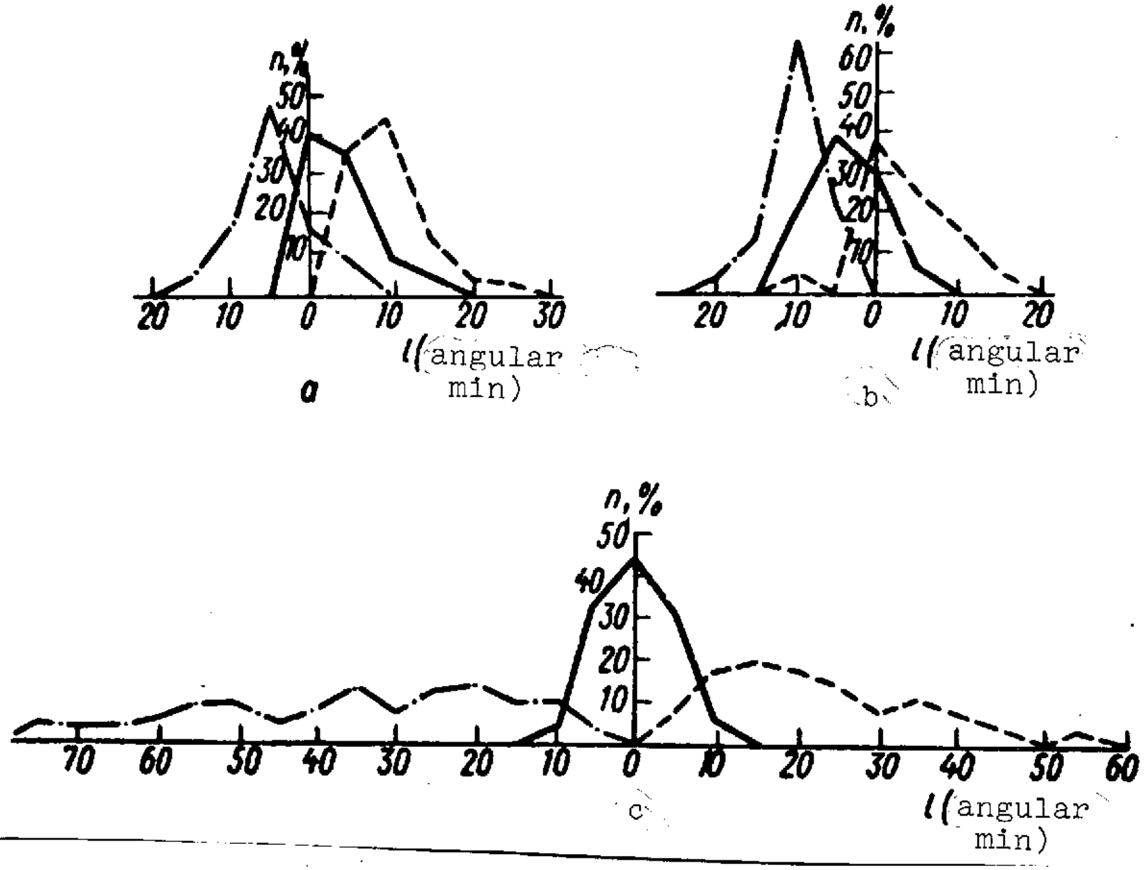

Fig. 2. Variation curves of PN and FOKN drift amplitude distribution curves of subjects with differing PN asymmetry: a--right sided subject (subject RM); b--left sided subject (subject ML); c--centrist (subject IM). Solid line, PN; dot-dast, FOKN (leftward movement of stripes); dashed, FOKN (rightward movement of stripes).

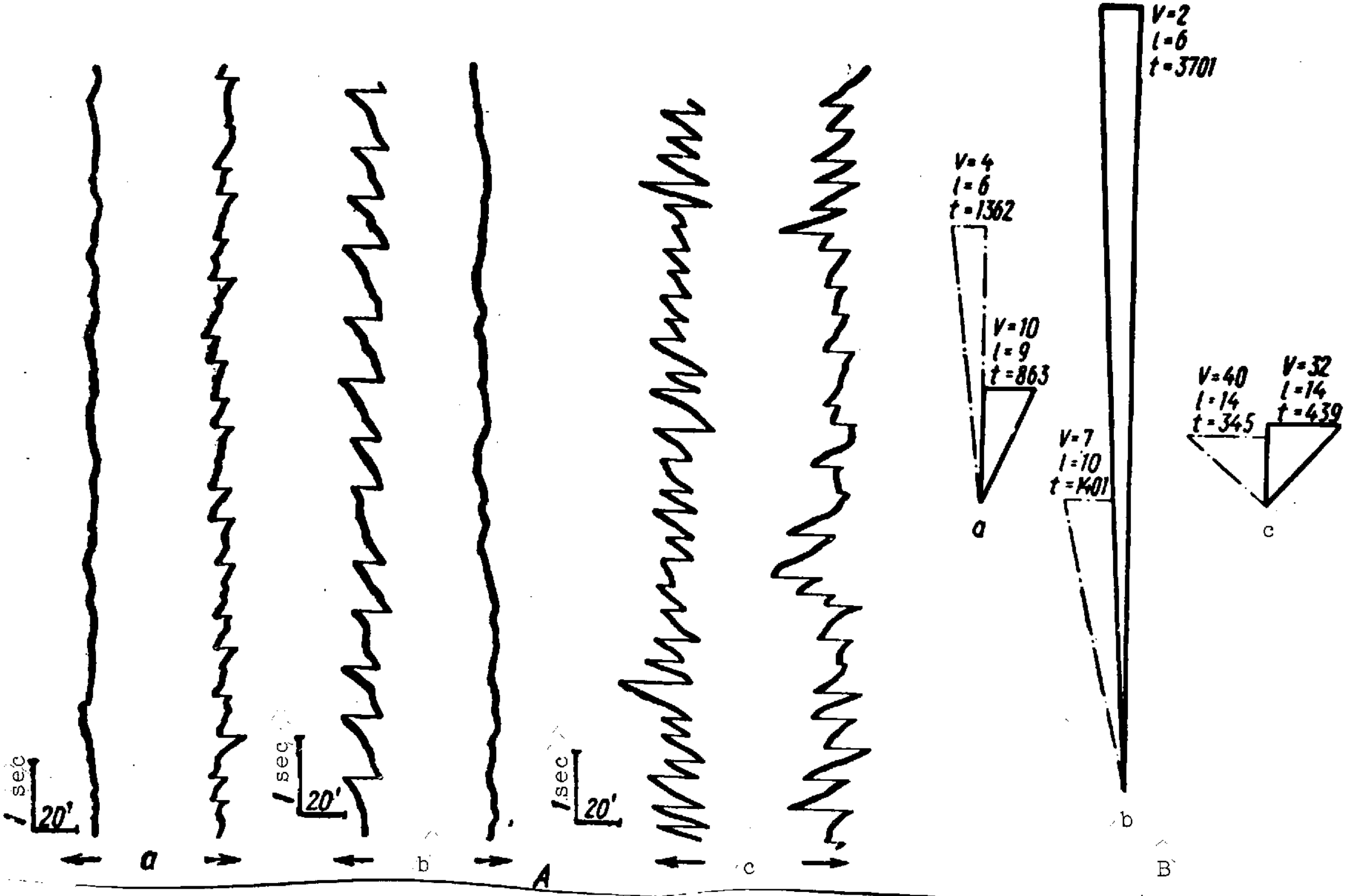

Fig. 3. FOKN with movement of stripes to left and to right: A. FOKN recordings: a--right sided subject (subject RM); b--left sided subject (subject ML); c--centrist (subject IM); ← stripe movement to left, → stripe movement to right; B. average FOKN cycle: a--right subject (subject RM); b--left sided subject (subject ML); c--centrist (subject IM). Solid line is stripe movement to the right; dot-dashed line, stripe movement to the left.

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hand, i.e., the direction of movement of the background, leading to a larger swing of the PN. This background direction was preserved in the subsequent tests.

Thus, all the material reported below refers to the typical FOKN.

QUANTITATIVE CHARACTERISTICS OF FOKN, COMPARED TO PN

Determination of the differences between fixation eye movements on a stationary and a moving background was of theoretical value, since precisely they could demonstrate the existence of FOKN, as a special type of eye movement. Therefore, first and foremost, we carried out statistical processing of the recordings, by the length, amplitude and rate of the FOKN and PN slow phases.[1] The average values of the FOKN slow phase parameters (for 8 subjects) turned out to be as follows: duration 930 msec, amplitude 20 angular min, rate 29 angular min/sec. The corresponding values of the PN, for the same group of subjects, were: 1490 msec, 4 angular min and 4 angular min/sec (see Table 1). The individual values of these PN and FOKN parameters also are presented in Table 1. A comparison of the data shows highly significant differences of both types of movements in all the parameters.

DEPENDENCE OF FOKN PARAMETERS ON PHYSICAL CHARACTERISTICS OF MOVING BACKGROUND (COMPARED WITH OKN)

It is known that one of the basic factors affecting the OKN parameters is the rate and frequency of the moving contrasts [7, 5, 14, 20, 17, and others]. This dependence was tested under the conditions of our tests. The subjects were given the task of tracking the moving contrasts from one edge of the screen to the other. The /33
rate of movement of the stripes was varied from 4-71 deg/sec; eight

[1]Since the return jumps bring the eyes to the initial position, their amplitudes correspond, on the average, to the amplitude of the slow phase of the fixation drifts of both PN and FOKN.

Table 1. Average Values of t, l and V of PN and "Typical FOKN" Drifts

№	Subject	PN M_1	"Typical FOKN" M_2	M_2-M_1
			t (msec)	
1	L.P.	3521	1058	—2468**
2	A.P.	1172	1020	—152*
3	I.M.	1019	509	—410**
4	B.A.	2080	1522	—558**
5	A.K.	1290	863	—427**
6	N.E.	702	439	—263**
7	S.I.	1566	1037	—529**
8	M.L.	1400	1060	—340**
	Ave.	1490	930	
			l (angular min)	
1	L.P.	4	27	23**
2	A.P.	6	13	7**
3	I.M.	3	27	24**
4	B.A.	5	28	23**
5	A.K.	3	9	6
6	N.E.	5	14	9**
7	S.I.	2	16	14**
8	M.L.	4	9	5*
	Ave.	4	20	
			V (angular min/sec)	
1	L.P.	3	31	28**
2	A.P.	3	14	11**
3	I.M.	4	62	58**
4	B.A.	3	23	20**
5	A.K.	4	11	7*
6	N.E.	9	33	24**
7	S.I.	2	18	16**
8	M.L.	3	11	8**
	Ave.	4	29	

* $p<0.05$.
** $p<0.001$.

different speeds were studied overall:

V_1 = 4 deg/sec	V_5 = 33 deg/sec
V_2 = 11 deg/sec	V_6 = 43 deg/sec
V_3 = 14 deg/sec	V_7 = 59 deg/sec
V_4 = 18 deg/sec	V_8 = 71 deg/sec;

their frequencies changed together with the speed. The results obtained are presented in Fig. 4, a, b, in the form of curves of slow /35 phase rate and OKN cycle frequency, respectively, vs. moving contrast rate and frequency. As is evident from the curves, at low contrast speeds, the eye movement speed almost coincides with it; this is retained, right up to values of 20-30 deg/sec (for frequency, the coincidenc is observed, right up to 90 cycles per min, Fig. 4b). With further increase in contrast speed, the eyes begin to lag behind; nevertheless, the slow phase rate and OKN cycle frequency increase, right up to 45 deg/sec (to a frequency of 200 cycles per min). A still greater increase in contrast speed leads to an abrupt slowing down of the eye movements (the curves abruptly drop downward). The results described coincide in general with data in the literature (see above).

Since FOKN is a special form of nystagmus, which also develops during movement of optical stimulation, it would be natural to answer the question, as to whether or not the physical characteristics of this stimulation (primarily its rate and frequency) affect the FOKN parameters. For this purpose, a special series was conducted with three right sided subjects (correspondingly, the stripes moved to the right). It turned out as a result that, with change in contrast speed, in the range from 14 to 240 deg/sec, the average speed of the FOKN slow phases for these subjects were constant, at 19 angular min/sec. The FOKN cycle amplitude and frequency also were retained. These results are presented in the curves in Figs. 4c, d and e (in all graphs, the column to the left of the ordinate designates the corresponding characteristics of the PN slow phases). Total (for 3 subjects) variation curves of the FOKN slow phase amplitude distribution, for 3 object speeds (V_1, V_4, V_8) are presented in Fig. 4f. The curves demonstrate their practical identity.

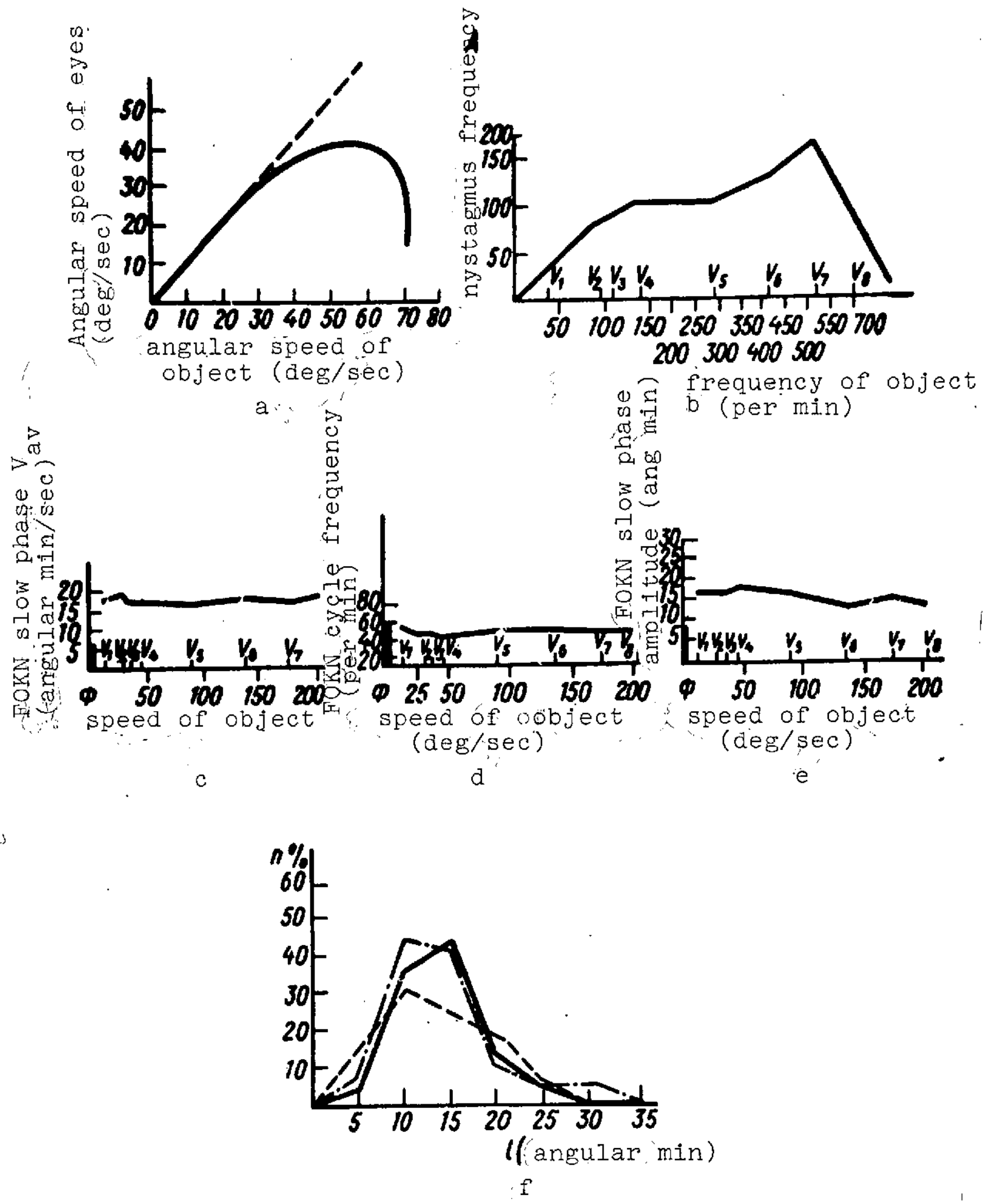

Fig. 4. Basic OKN and FOKN parameters vs. physical characteristics of moving contrasts. Relation: a--OKN slow phase angular speed; b--OKN cycle frequency; c--FOKN slow phase angular speed; d--FOKN cycle frequency; e--FOKN cycle amplitude vs. moving contrast rate and frequency; f--variation curves of FOKN slow phase amplitude distribution at various moving contrast speeds (total data for 2 subjects); dashed line is speed V_1; dot-dash is speed V_4; solid is speed V_8.

DEPENDENCE OF FOKN PARAMETERS ON PHYSICAL CHARACTERISTICS OF FIXATION POINT

In distinction from the moving background, the physical characteristics of the fixation point disclosed a significant effect on the FOKN parameters. As a special series of experiments demonstrated, an increase in size and brightness of the points led to suppression of FOKN: to a decrease in slow phase amplitude and speed; on the contrary, attenuation of the points leads to a swing of FOKN; in attempts to fix the image point, a still greater swing of the FOKN is observed, which gradually changes to tracking movements (OKN) (Figs. 5A, B).

PN AND FOKN IN STATE OF ALCOHOLIC INTOXICATION /37

As has already been stated, special tests were carried out with 2 subjects, for the purpose of revealing the effect of alcohol on fixation movements. Alcohol frequently is used for study of mechanisms of regulation of various eye movements. Concerning fixation movements, we succeeded in finding only one reference to the effect of alcohol on them: after taking it, an increased spontaneous movement appeared, especially when turning the eyes sharply to the side [9].

A PN recording of a right sided subject (RM) in the normal state and in the state of alcoholic intoxication is presented in Fig. 6. A FOKN recording in the normal state also is given for comparison. An increase of PN slow phase amplitude and speed over the normal PN, as well as a great similarity of the "alcoholic" PN with the typical FOKN are noted. We fail to obtain a OKN recording of subjects in the state of alcoholic intoxication: turning on the moving contrasts slowly led to the appearance of severe dizziness, nausea and the impossibility of maintaining stable fixation; as a rule, the subjects refused further participation in the test.

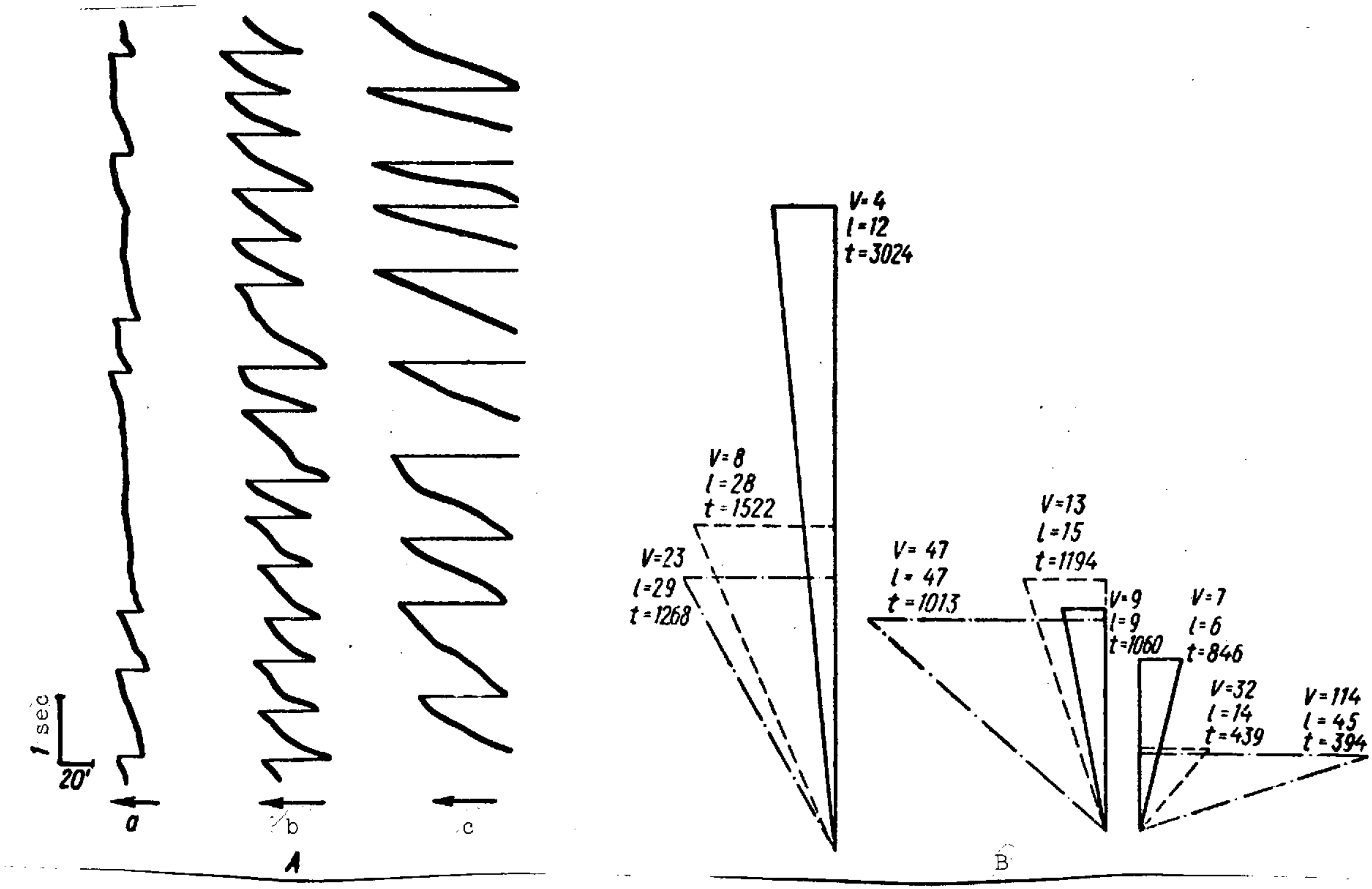

Fig. 5. FOKN cycles vs. angular dimensions and brightness of fixation point. A. FOKN recordings: a--large point; b--scarcely noticeable point; c--"I do not see the point." Subject ML, left sided, the contrasts moved to the left in all recordings. The breaks in recording c are connected with the beam going beyond the screen of the recording device. B. Average FOKN cycles of 3 different subjects: solid line, large point; dashed, medium point; dot-dash, scarcely noticeable point.

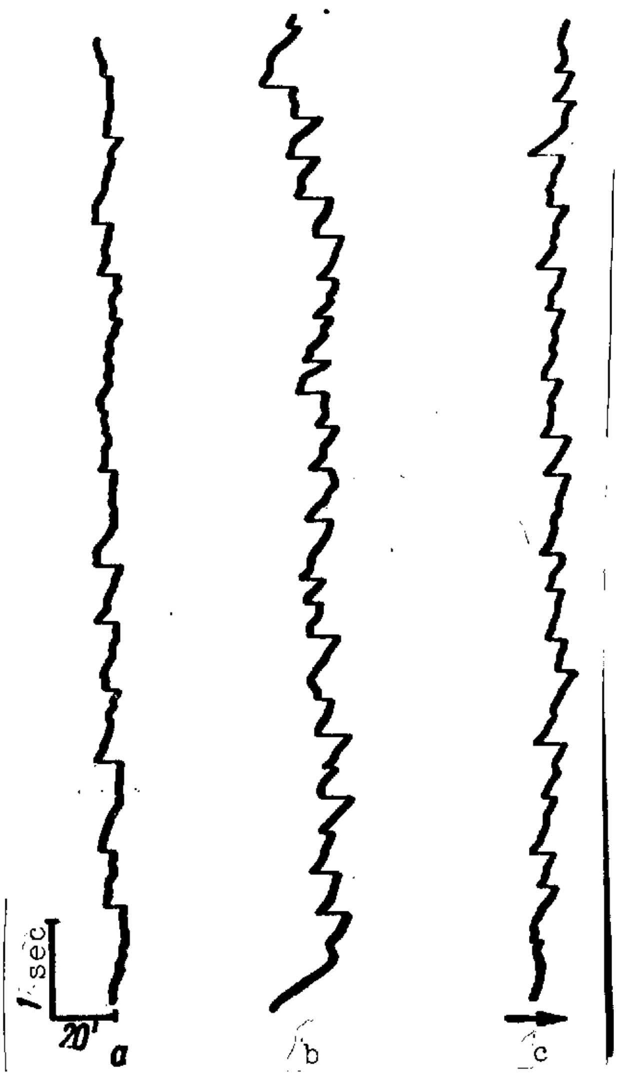

Fig. 6. Comparative normal PN, PN in a state of alcoholic intoxication and FOKN recordings (subject RM, right sided): a--normal PN; b--PN in state of alcoholic intoxication; c--FOKN (stripe movement to the right).

POSSIBLE MECHANISMS OF FOKN

We have already expressed a hypothesis on the possible nature and mechanisms of FOKN [4]. The new facts do not contradict the initial concepts; therefore, we repeat, only with small changes in the analysis given in the work indicated.

It might be thought that at least 3 different mechanisms participate in formation of FOKN: centers 1 of involuntary nystagmus (nystagmogenic center); 2 involuntary fixation; 3 voluntary fixation. /38

One of the first concepts of the existence of a nystagmogenic center is encountered in G. Rademaker and J. Ter Braak [18], who localized it in the region of the vestibular and oculomotor subcortical nuclei. Confirmation of the existence of this center was obtained later, in the studies of F. Bergmann, A. Costin, J. Gutman and M. Chaimovitz [10] and J. Wolfe [22], who produced horizontal nystagmus in the dark (central nystagmus), by stimulating the nucleus of the anterior diencephalon. Central nystagmus developed in the light, only with the additional effect of the moving contrasts. Two circumstances are of particular interest to us. First, central nystagmus is increased, in the event the direction of movement of the contrast coincides with the direction of the central nystagmus slow phases in the dark; otherwise, inhibition of the central nystagmus set in. Second, the speed of movement of the contrast did not have an effect on the central nystagmus rhythm. Both facts are in good agreement with our results, namely: with a swing of the PN (typical FOKN), in coincidence of the direction of movement of the contrast with the predominant direction of PN drifts (with their asymmetry) and suppression of PN (suppressed FOKN) in the opposite case; and the absence of an effect of the physical characteristics of the contrasts (speeds, frequencies) on the FOKN rhythm. From this, it can be considered that the subcortical nystagmogenic center is one of the mechanisms of both PN and FOKN. It might be thought that this center is the source of only smooth fixation drifts (i.e., it belongs to the tonic system of the oculomotor apparatus [6]). Rapid PN and FOKN phases are the result of the work of other mechanisms of the oculomotor apparatus phasic system (see [6]).

Involuntary fixation is a reflex response to a visual stimulus or an oculomotor static reflex of the eyes [21, 17, 11, and others]. The unique riveting of the eyes to an object, of children in the first month of life [15] and the case of spastic fixation with damaged frontal centers, when the patient cannot tear the gaze away from an object perceived [2] are clear examples of such reflex movements.

Voluntary fixation occurs, as a full-value, purposeful action, and it is expressed by the ability of a normal adult person to voluntarily maintain or stop fixation on a given point in space. /39
While involuntary fixation is started by the action of an external stimulus, the start of voluntary fixation is inside the body, as it were. It is determined by the purpose of the fixation.

The centers of both types of fixation have different localizations in the brain: the center of reflex, automatic fixation is in the occipital zones of fields 17, 18 and 19 of the visual cortex, according to Brodman; the center of voluntary or "volitional" fixation is in the frontal zone, the eighth field according to Brodman [2]. Both mechanisms function in normal visual work, and it is impossible to separate them in each individual fixation of the eyes, as a rule. More than that, a number of factors permit description of certain properties and singularities of the interaction of these mechanisms.

Under normal conditions, voluntary fixation is subordinate to the involuntary, which sanctions starting or stopping it. The examples of spastic fixation presented disclose a disruption of precisely this function of voluntary fixation. In turn, involuntary fixation emerges as a "technical background component" [1] of purposeful fixation. In the absence of this component, the latter cannot be accomplished successfully. Thus, in complete darkness, running together of the eyes is observed, exceeding the magnitude of normal fixation drifts by an order of magnitude, despite voluntary efforts of the subject to fix the eyes. Another proof is the impossibility of causing a tracking movement of the eyes (dynamic fixation) with-without a moving object. In both cases, failure of the action is explained by the absence of "supports" of the voluntary mechanism by the involuntary, which is put into operation only by an optical stimulus. The involuntary fixation mechanism showed up in our tests under ambiguous conditions: the stationary point "provoked" switching on of the static fixation and the moving stripes, switching on of dynamic fixation, or tracking. The voluntary determination of the subject to fix the stationary point, in accordance with instructions, decided the outcome of the conflict. Without such instructions, the eyes were subject to the moving contrasts, as physically stronger stimuli, and began to track them: FOKN changed into OKN cycles. Consequently, a "volitional fixation source" is one of the obligatory conditions for development of FOKN. However, as has already been stated, it can only be effective with the support of the involuntary or automatic fixation mechanism. This is demonstrated by the actual disappearance of FOKN (its transformation into OKN cycles) upon switching off the point (see Fig. 5A, c), as well as by the dependence of its parameters on the physical strength of the point stimulus. To the point, this latter fact discloses the na- /40 ture of the interaction of the involuntary (or automatic) fixation mechanism with the nystagmogenic center: the second can be suppressed by the first (by increasing the brightness of the point), or it can be "freed" from its influence (by decreasing the brightness of the point). In distinction from this, the voluntary fixation mechanism does not have direct "access" to the involuntary drift centers: efforts of the subject to increase the strictness of fixation are not reflected in the FOKN amplitude.

CONCLUSION

In the task of fixing a point on a background of moving contrasts, involuntary eye movements, fixation optokinetic nystagmus (FOKN) are observed. It differs from both physiological nystagmus (PN) and optokinetic nystagmus (OKN).

The characteristics of FOKN depend on the relationships of the direction of PN asymmetry and the moving contrasts. With coincidence of these directions, FOKN has the appearance of a swinging PN and, when they are in opposite directions, the appearance of suppressed PN.

A characteristic feature of FOKN is the absence of a dependence of the slow phase speed on the speed of movement of the contrasts. This forces one to assume that this type of nystagmus is of a subcortical nature. In distinction from the moving background, the physical characteristics of the point have an effect on the FOKN properties, leading to either a strengthening of it (decrease in size and brightness of the point) or to suppression of it (increase in size and brightness of the point). The results obtained lead to the hypothesis of participation of the subcortical involuntary nystagmus center, the occipital involuntary center and the frontal voluntary fixation center in formation of FOKN, and it also results in description of certain features of the interaction of these centers.

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